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Residual Nitrate and Mineralizable Soil Nitrogen in Relation to Nitrogen Uptake by Irrigated Sugarbeets[1]

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ABSTRACT

Previously reported studies on N fertilization of sugarbeets (*Beta vulgaris* L.) in southern Idaho revealed considerable variation among sites in amounts of residual soil NO_3 and N mineralized during short-term laboratory incubations. Consequently, the amount of N fertilizer needed to achieve near-maximum yields of sucrose differed markedly. The purpose of this study was to determine the feasibility of estimating amounts of N mineralized in the root zone during the season, taking into account site variations in temperature and soil water regimes. Residual soil NO_3^--N and mineralizable N to approximate rooting depth were estimated for 21 field sites in 1971 and six sites in 1972. The relative contributions of these two N sources to total N uptake by the crop, in the absence of applied fertilizer N, were then assessed. Estimates of N mineralized in the upper 45-cm soil layer for each successive month, ΔN, over a 6-month period were derived using the expression, $\Delta N/\Delta t = kWN$ (k = fraction of N mineralized during each month, Δt, adjusted for average air temperature; and W = the estimated soil water content expressed as a fraction of the available water storage capacity). Resulting estimates of the fraction of potentially mineralizable N converted to $(NO_3^- + NH_4^+)$-N between 1 April and 30 September ranged from 0.15 to 0.22 (mean ± S.D. = 0.18 ± 0.02) in 1971 and 1972. On the average, mature sugarbeets recovered about 73% of the estimated N mineralized (6 months) plus residual NO_3^--N. The relative contributions of these two sources of soil derived N, respectively, were approximately 66 and 75%, as estimated from multiple regression analyses.

Additional index words: Temperature, Soil water content, N use efficiency, N requirement.

AMOUNTS of residual soil NO_3 reflect management, N fertilization, and irrigation practices and influence the optimal level of N fertilizer needed for sugarbeets, (*Beta vulgaris* L.) (1, 2, 3, 4, 5). The remainder of the soil derived N is supplied through mineralization of soil organic N (1, 2, 3, 5, 11). Hence, both residual NO_3 and mineralizable N must be measured to evaluate differences in N-supplying capacities among soils. This has been demonstrated clearly by Carter and associates (1, 2, 3) based on extensive field studies involving N fertilizer rates with irrigated sugarbeets.

Amounts of mineralizable N potentially available to the crop may be assessed by various means. Carter et al. (1) incubated soils for 3 weeks at 30C and optimal water content (field capacity). Considering N uptake as a function of the amounts of N mineralized, residual nitrate, and N supplied by fertilizer, together with a reliable estimate of the optimal N requirement of sugarbeets (5.5 ± 0.5 kg/metric ton), these investigators and their coworkers (1, 2) developed a procedure for predicting N fertilizer needs that offers a basis for minimizing overuse of N and the associated adverse effects on sucrose yield and quality.

Another approach to estimating the contribution of N mineralization of soil organic N has been suggested by Stanford et al. (11). The potentially mineralizable N, N_0, considered as a more or less discrete fraction of total organic N, is estimated from amounts of N mineralized in successive incubations (8, 12) and is an estimate of the amount of N that will mineralize in infinite time under optimal temperature (35C) and optimal soil water content (approximately field capacity). The mineralization potential, N_0, may pro-

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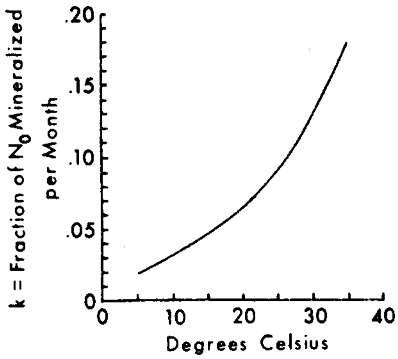

Fig. 1. Fraction of N mineralized per month, k, in relation to temperature (k was estimated graphically for observed average monthly air temperatures).

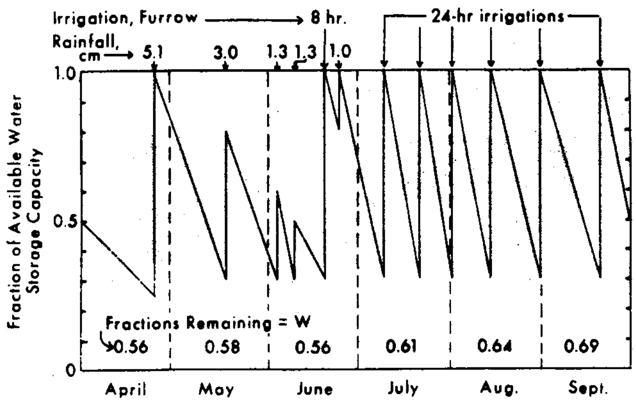

Fig. 2. An example of the graphic (grid-counting) procedure used for estimating the monthly average available water supply expressed as a fraction of the water storage capacity (site 106, 1971).

vide a basis for estimating how much N is mineralized during the crop season under specified temperature and soil water regimes, since these factors exert a dominant influence on mineralization rates (9, 10, 11).

Using soils from field studies (1, 2, 3, 8) on N fertilization of irrigated sugarbeets in Idaho, the nitrogen mineralization potentials of soils from each experimental site (before N fertilization) were determined by the ARS, Beltsville, Md. The purpose of this report is to evaluate the feasibility of estimating N mineralized during the cropping season from a knowledge of N mineralization potential, N_0, average monthly temperatures, and estimates of average monthly soil water regimes. This evaluation, based on data obtained from the plots that received no N fertilizer, involved determining the relation between N uptake by sugarbeets and amounts of available soil N (residual NO_3 and estimated N mineralized).

MATERIALS AND METHODS

Soil and Plant N Measurements

During 1971, 32 irrigated N-rate experiments were conducted in southern Idaho. Detailed classification, potential rooting depth, previous crop history, and soil characteristics (pH, percent N, and percent organic matter) for most of these soils were reported by Carter et al. (2). Before applying fertilizer, each

Table 1. Estimation of percent of N_0 (mineralization potential) mineralized based on average monthly temperature and soil water regimes (site 7, 1971).

			N_0		
Month, 1971	k	W	Present initially (N)	Remaining after each month	Mineralized per month
			%		
Apr.	0.033	0.60	100	98	2.0
May	0.047	0.53	98	95.6	2.4
June	0.053	0.67	95.6	92.2	3.4
July	0.080	0.64	92.2	87.5	4.7
Aug.	0.088	0.74	87.5	81.8	5.7
Sept.	0.045	0.73	81.8	79.1	2.7
			Total % of N_0 mineralized		20.9

site was sampled in 15-cm increments to a depth of 45 cm. Corresponding 15-cm layers for 24 cores per site were composited. Deeper samplings of 30-cm increments were taken where the root zone was not restricted to 45 cm by a hardpan.

In 1972, eight irrigated N-rate experiments were conducted on six soil types. Results from these experiments have been reported (3) along with details of soil sampling methods, soil classification, previous crop, and surface soil properties.

The NO_3 content of all soil layers was determined as described in earlier reports (1, 2). The N mineralization potential, N_0, was estimated according to methods described in earlier publications (8, 13).

Methods of obtaining yields of total dry matter (tops + crowns + roots), beets, and sucrose have been described (1, 2). Total N content of dry matter was based on separate determinations for the tops, roots, and crowns and does not include the estimated N content of fibrous roots as was done in earlier publications (1, 2, 3).

Effect of Temperature on N Mineralization

The temperature coefficient, Q_{10}, of N mineralization is 2 in the range of 5 to 35C (10), denoting a two-fold change in the mineralization rate associated with a 10C shift in temperature. For a given temperature, k is the mineralization rate constant in the first order expression, $-dN/dt = kN$ (12).

In this study, we used average monthly air temperatures, reported by local climatological stations, as approximate estimates of soil temperatures for the period 1 April through 30 September. The relation of k ($month^{-1}$) and temperature used in making our estimates is shown in Fig. 1. The curve depicts a Q_{10} of 2 and assumes an average k-value (35C) of 0.18 $month^{-1}$ (0.045 $week^{-1}$ $\times$ 4 weeks). Based on a large number of soils, the average k for 35C has been reported to be 0.054 $\pm$ 0.009. We arbitrarily chose the lower limit, 0.045 $week^{-1}$ or 0-18 $month^{-1}$ for our estimates in this study. Using this base value, k_{25C} = 0.09, k_{15C} = 0.045, and k_{5C} = 0.023. Values of k for successive average monthly air temperatures were interprolated from the curve (Fig. 1) in estimating temperature effects on N mineralization as described below.

Estimating Effects of Soil Water Fluctuations on N Mineralization

The N mineralization rate is linearly related to the content of plant-available soil water in the range from field capacity to wilting percentage (9). Expressed on a relative basis, i.e., setting maximum mineralization rate and optimal water content equal to one, the slope of the regression is approximately one for soils of differing textures and organic matter contents (9).

For each of the sites, irrigation dates and rainfall records were recorded. This information was used in estimating the average fraction, W, of available soil water present in the root zone during each successive month. In general, we assumed that each irrigation replenished the available water storage capacity, i.e., W = 1. Effects of rainfall were estimated, although this contribution was relatively small, except for occasions in the first 2 or 3 months of the growing season. The value of W on 1 April was estimated arbitrarily from cumulative antecedent rainfall

Table 2. Plant composition and yield data from zero-N plots of sugarbeet N-rate experiments (Idaho, 1971).

Site no.	Soil type†	Yields TDM‡	Roots	Sucrose	Sucrose	N Uptake	TDM
		metric tons/ha			%	kg/ha	%
1	Schism sil	24.8	64.9	11.0	17.0	318	1.28
2	Garbutt sil	17.5	49.4	8.4	17.0	172	0.98
3	Purdam sil	27.5	82.3	12.9	15.7	421	1.53
4	Greenleaf sil	20.7	63.7	9.6	15.0	318	1.53
6	Elijah sil	21.8	65.0	10.9	16.8	286	1.31
7	Power sil	18.4	59.0	10.4	17.7	124	0.67
8	(unknown) scl	18.6	57.2	9.4	16.4	229	1.23
101	Declo sil	14.2	46.2	8.3	17.9	111	0.78
102	Portneuf sil	11.7	36.9	6.5	17.7	108	0.92
103	Portneuf sil	18.5	57.8	10.4	18.0	159	0.86
104	Portneuf sil	18.5	55.4	10.2	18.4	155	0.83
105	Portneuf sil	18.3	46.4	8.7	18.7	194	1.06
106	Portneuf sil	20.4	54.4	9.6	17.8	203	0.99
151	Portneuf sil	18.7	52.8	8.4	16.1	258	1.38
152	Decker l	18.3	49.3	7.9	16.0	265	1.45
153	Portneuf sil	14.0	35.6	6.0	16.8	191	1.36
155	Minidoka sil	9.6	24.4	3.7	15.2	204	2.13
156	Kimama sil	10.0	29.5	5.6	18.9	82	0.82
157	Portneuf sil	14.6	41.0	6.6	16.1	218	1.50
201	Portneuf sil	15.7	43.2	7.4	17.1	171	1.09
202	Neeley sil	14.5	46.9	8.8	18.9	128	0.89
203	Declo l	7.8	22.8	3.8	16.9	151	1.94
204	Broncho l	15.9	38.6	6.9	18.0	226	1.42
205	Portneuf sil	16.5	50.3	7.9	15.7	253	1.53
206	Portneuf sil	16.7	48.5	8.4	17.4	265	1.58
207	Declo sil	19.0	55.6	8.8	15.9	279	1.47
208	Ammon sil	19.6	60.3	9.8	16.3	292	1.49
209	Pancheri sil	19.5	52.2	8.2	15.8	308	1.58
210	Pancheri sil	18.0	51.1	8.9	17.4	285	1.58
211	Bannock l	16.9	48.7	8.7	17.9	165	0.98

† For detailed classification of soils, see Soil Series of the United States: Their Taxonomic classification. Soil Conservation Service, USDA. Aug. 1972. Site 1 received 110 kg N/ha in June; site 3 probably received N fertilizer; site 102 had poor stand and was severely cultivated late in season; site 104 received about 30 kg N/ha in irrigation water in Aug.; sites 153 and 155 included several adverse unidentified conditions; site 203 had uneven stand because of root maggots; site 209 received manure after soil sampling. ‡ Harvested root, crown, and tops (excluding fibrous roots).

Table 3. Plant composition and yield data from zero-N plots of sugarbeet N-rate experiments (Idaho, 1972).

Site no.	Soil type†	Yields TDM‡	Roots	Sucrose	Sucrose	N Uptake	TDM
		metric tons/ha			%	kg/ha	%
P10	Truesdale l	18.6	59.9	9.9	16.5	234	1.26
P20	Baham vfsl	23.0	70.6	12.2	17.3	245	1.05
P21	Power sil	21.8	64.7	11.2	17.4	251	1.15
P110	Portneuf sil	20.3	58.3	9.6	16.4	265	1.30
P111	Portneuf sil	11.7	40.0	6.6	16.5	105	0.90
P160	Declo l	14.9	44.5	7.7	17.4	155	1.04
P220	Portneuf sil	11.8	37.4	6.7	17.9	109	0.93
P222	Pancheri sil	14.5	39.9	6.6	16.5	214	1.48

† See first footnote in Table 1. Site P10 had insufficient irrigation in July and Aug.; site P160 had variable stand. ‡ Harvested root, crown, and tops (excluding fibrous roots).

for January, February, and March. Among sites, the range in antecedent rainfall was 5 to 14 cm in 1971 and 1972. The corresponding initial values of W were considered to be 0.5 and 0.8, and intermediate values of W on 1 April for each site were estimated by assuming a linear relation between antecedent rainfall and W within the indicated limits. In the interval between irrigations, we assumed 70% depletion of the available water present after the preceding irrigation.

The graphic procedure used for estimating W is illustrated in Fig. 2. Months are delineated by vertical dashed lines. Estimates of water replenishment by irrigation or rainfall (vertical

Table 4. NO_3-N present before planting to approximate depth of rooting, and N mineralization data (kg/ha).

Site no.	Weather station	NO_3-N Depth	Amount in root zone	N mineralization potential, N_0 (45-cm depth)	N mineralized (Apr. through Sept.) Adjusted for temp.	Adjusted for soil water and temp.
		cm				
			1971 Experiments			
2	Grandview	150	83	1,022	318	228
4	Kuna	90	200	825	232	164
6	Kuna	45	174	1,067	300	212
7	Emmett	90	114	643	194	135
8	Caldwell	60	151	915	290	202
101	Hazelton	60	52	800	217	139
103	Hazelton	60	77	859	233	163
105	Jerome	60	117	895	262	186
106	Twin Falls	60	111	859	237	151
151	Burley	45	159	1,047	269	189
152	Oakley	60	137	1,020	268	183
156	Paul	60	36	742	193	133
157	Burley	45	99	1,045	269	187
201	Minidoka	45	76	614	149	103
202	Minidoka	150	184	668	163	112
204	Aberdeen	45	66	847	206	154
205	Aberdeen	60	136	856	209	148
206	Aberdeen	45	192	899	219	156
207	Aberdeen	60	202	1,043	253	175
208	Aberdeen	150	243	1,020	248	168
211	Aberdeen	45	57	879	217	132
			1972 Experiments			
P20	Caldwell	60	130	695	216	144
P21	Caldwell	60	130	839	261	169
P110	Hazelton	60	128	912	247	171
P111	Twin Falls	60	18	787	214	157
P160	Burley	60	66	937	240	162
P220	Aberdeen	60	50	776	186	123
P222	Aberdeen	45	49	952	228	155

Estimating Combined Effects of Temperature and Soil Water on N Mineralization

Estimates of the cumulative fraction of N_o mineralized during the 6-month period, April through September, were based on monthly averages of air temperature and estimated fraction of available water storage capacity as indicated above. Estimates of amounts of N mineralized during each month, ΔN, were obtained from the rate expression, $\Delta N/\Delta t = kWN$. The factors, k and W, were explained earlier. Initially, $N = N_o$ (N_o is the N mineralization capacity of the 0- to 45-cm soil layer). For convenience in calculations, N_o initially is assigned a value of 100. During the first month, as illustrated in Table 1, $kWN = 2.0$ (last column). For successive months, N_o is reduced by the cumulative amount of N mineralized in previous months. In the example given (Table 1), the cumulative fraction of N_o mineralized during 6 months was 0.209. To estimate N actually mineralized, this fraction was multiplied by N_o, e.g., 643 kg/ha $\times$ 0.209 = 135 kg/ha (site 7, 1971).

RESULTS AND DISCUSSION

Yield of roots, sucrose (percent sucrose $\times$ yield of roots), and N composition of total dry matter (TDM) are presented in Tables 2 and 3. As indicated in footnotes, results from several of the experiments may be questionable, although, as shown later, these data were useful in establishing the optimal N content of sugarbeets for maximum yield.

In Table 4, locations of climatological stations closest to the experimental sites are given. Mean air temperature and rainfall recorded at these stations were used in adjusting N mineralization values. Also

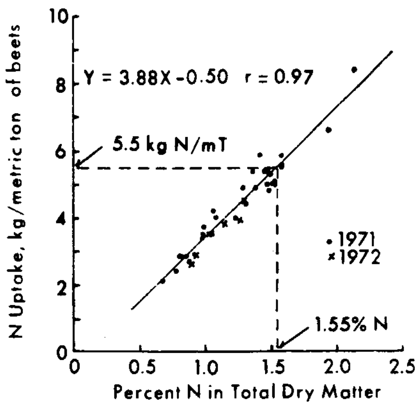

Fig. 3. N uptake (kg/metric ton of beets) in relation to percent N in total dry matter.

depths of sampling. These depths approximate the root zone and differ because of a restrictive hardpan layer of varying depth among sites.

Degree of N Sufficiency as Revealed by N Uptake

Carter et al. (1), have established that maximum yield of sucrose or total dry matter is associated with a total uptake of approximately 5.5 kg of N/ton of beets. This observation offers a direct means of determining the degree of adequacy of soil derived N as it varies among sites (Fig. 3). Here, the data from all sites (see Tables 2 and 3) were used to depict the regression of kg N/metric ton on percent N in the TDM for 1971 and 1972 zero-N plots. Since the regression coefficients for 1971 and 1972 did not differ significantly, only the pooled regression is shown in Fig. 3. As estimated from the pooled regression, 5.5 kg N/metric ton corresponds to 1.55 percent N in the TDM. This percentage of N, associated with near maximum yield, is close to the value of 1.6% estimated from California results (7). In comparing sucrose yields and percent N (Tables 2 and 3), it becomes evident, therefore, that the soil N supplied by most of the sites was inadequate for maximum yield of sucrose. Near adequacy of N is indicated for several sites, associated with a broad range (6 to 10 metric ton/ha) of attainable sucrose yields. From combined results for 1971 and 1972, the regression of "percent N in TDM" on "percent sucrose" is % N = 5.2 to 0.24 percent sucrose ($r = -0.71$).

Contribution of Residual Nitrate and Mineralizable Soil N to Plants

In 1971 the amounts of residual NO_3-N estimated for sites given in Table 4 ranged from 36 to 243 kg/ha (average, 127). Corresponding ranges for total N uptake (Table 2) were 82 to 318 kg/ha (average, 209). Assuming complete recovery, an average 61% of total N uptake might be attributed to residual NO_3. In 1972 (Table 4) root zone NO_3-N ranged from 18 to 130 kg/ha (average, 82) and N uptake (Table 3) ranged from 105 to 265 kg/ha (average,

Table 5. Cumulative percentage of potentially mineralizable N mineralized during 6 months (Apr.-Sept.) as affected by average monthly fluctuations in temperature and available soil water.

Site no.	% of N_0 mineralized, corrected for: Temp., T	Temp. and soil water, S
1971		
2	31.2	22.3
4	28.1	19.8
6	28.1	19.8
7	30.1	20.9
8	31.7	22.0
101	27.2	17.4
103	27.2	18.9
105	29.3	20.8
106	27.5	17.6
151	25.7	18.1
152	26.3	17.9
156	26.2	17.9
157	25.7	17.9
201	24.3	16.7
202	24.3	16.7
204	24.3	18.1
205	24.3	17.3
206	24.3	17.3
207	24.3	16.8
208	24.3	16.5
211	27.2	15.1
S.D.†	(2.4)	(1.9)
1972		
P20	31.1	20.7
P21	31.1	20.1
P110	27.1	18.7
P111	27.2	20.0
P160	25.6	17.3
P220	24.0	15.8
P222	24.0	16.3
S.D.†	(3.0)	(2.0)

† S.D. = Standard deviation.

ently was 43%. The remaining N in the crop was derived largely from soil N mineralized during the growing season.

The amount of soil N mineralized in the course of the season is dominantly influenced by temperature and soil water content, as mentioned earlier. These effects were estimated as outlined in Table 1, based on monthly adjustments derived from average air temperatures and estimated average fractions of potentially available soil water present during each month. The estimated percentages of N_0 mineralized from April through September are shown in Table 5. In 1971 and 1972, sites 2 through 21, 101 through 160, and 201 through 222, respectively, occurred in the western, central, and eastern sections of southern Idaho bordering the Snake River. Corresponding average N mineralization percentages (± standard deviation) as influenced by temperature alone, were 30.0 ± 1.5 (eastern), 26.8 ± 1.1 (central), and 24.5 ± 0.9 (eastern). Thus, differences among geographical locations account for much of the overall variation in temperature effects on N mineralization.

In both years, total N uptake was correlated significantly with amounts of NO_3-N in the root zone (Table 6, r_{y1}). In 1971 and 1971-72 combined, N uptake also was significantly correlated with N_0 and with estimated N mineralized (Table 6, r_{y2}). Because the variables, X_1 and X_2, are not strongly related (column r_{12}), their independent contributions to Y (N uptake) can be evaluated with reasonable confidence

Table 6. Regression equations and correlation coefficients depicting relationships of N uptake (Y, kg/ha) to NO_3-N in the root zone (X_1, kg/ha) and to X_2 (N mineralization potential, N_0, or estimated N mineralized during the cropping season, kg/ha).

Year	No. of sites	Regression equation	Correlation coefficients† R	r_{y1}	r_{y2}	r_{12}	$r_{y1.2}$	$r_{y2.1}$
		A. (X_2 = N mineralization potential, N_0)						
1971	21	(1) $Y = 0.67\,X_1 + 0.21\,X_2 - 61.7$	0.84**	0.74**	0.64**	0.36	0.71**	0.60**
1972	7	(2) $Y = 1.04\,X_1 + 0.19\,X_2 - 53.1$	0.82*	0.80*	0.15	0.18	0.83*	0.43
Years combined	28	(3) $Y = 0.72\,X_1 + 0.18\,X_2 - 37.1$	0.82**	0.75**	0.56**	0.31	0.73**	0.51**
		B. (X_2 = N mineralized, 6 months, estimated)						
1971	21	(4) $Y = 0.75\,X_1 + 0.69\,X_2 + 1.3$	0.80**	0.74**	0.49**	0.25	0.73**	0.47**
1972	7	(5) $Y = 0.21\,X_1 + 0.90\,X_2 - 44.4$	0.80*	0.80*	0.39	0.18	0.89*	0.50
Years combined	28	(6) $Y = 0.75\,X_1 + 0.66\,X_2 + 10.6$	0.80**	0.75**	0.47**	0.28	0.73**	0.42*

* 5% level of significance. ** 1% level.
† R = multiple correlation coefficient; y = dependent variable; subscripts 1 and 2 denote X_1 and X_2, respectively; $r_{y1.2}$ and $r_{y2.1}$ denote partial correlation coefficients.

relation coefficient relating N uptake to residual NO_3 ($r_{y1.2}$) and N uptake to N_0 or estimated N mineralized ($r_{y2.1}$) for individual and combined years were significant except in 1972, which involved only seven sites. Statistical methods and symbols are those of Snedecor (6).

Results in Table 6 verify the earlier conclusion of Carter (1, 2, 3) that both residual NO_3-N and mineralizable N contribute to N uptake by sugarbeets. It is important to recognize that N_0 constitutes a relative index of N mineralization capacity, unaffected by climatic factors, while N mineralized is an estimate of the N actually derived from N_0 under prevailing temperature and water regimes. Hence, regression equations 4 and 6 (Table 6) are of particular interest. The reliability of equation 5 is questionable since it is based on only seven sites involving a relatively narrow range of N_0. The regression coefficients in equation 4 and 6 indicate similar relative contributions, to N uptake, of residual NO_3 (X_1) and estimated N mineralized during 6 months (X_2). A plot of observed vs. calculated (equation 4) N uptake values (Fig. 4) indicates several large deviations between measured and predicted values for the 1971 data.

These deviations are the net result of several combined sources of error such as: estimating residual NO_3 and N_0 from composited soil cores taken from the entire experimental area rather than individual check plots; estimating soil temperatures and soil water indirectly; and sampling and analytical errors in estimating the N uptake. The general success of equation 4 is encouraging considering these large sources of error.

Although there is no absolute basis for independently evaluating the percent recovery (efficiency) of residual NO_3-N and mineralized N, regression coefficients (equations 4 and 6, Table 6) suggest similar relative contributions of N from these two sources. The regressions of N uptake (Y) on combined residual NO_3-N and estimated N mineralized ($X_1 + X_2$) are as follows:

1971: $Y = 0.73\,(X_1 + X_2) - 2.6$ $(r = 0.80)$;

1972: $Y = 1.09\,(X_1 + X_2) - 6.0$ $(r = 0.87)$;

and

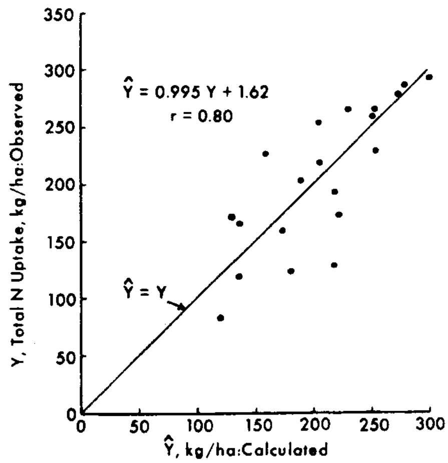

Fig. 4. Observed (Y) vs. calculated ($\hat{Y}$) N uptake by sugarbeets where $\hat{Y} = 0.75X_1 + 0.69X_2 + 1.3$ (X_1 = residual NO_3-N in root zone; X_2 = estimated N mineralized under prevailing temperature and water regimes).

years combined: $Y = 0.73\,(X_1 + X_2) + 5.3$ $(r = 0.80)$.

The regression coefficients indicate an overall average efficiency of about 73% which approximates the recovery that might be expected from near optimal N fertilizer rates applied to sugarbeets (1).

CONCLUSIONS

This study evaluates one approach to estimating the contributions of mineralizable soil N to the growing crops in the field. The potentially mineralizable soil N is first determined in the laboratory, based on analysis of soils sampled from the portion of the root zone that contributes to N mineralization. In southern Idaho soils, most of the mineralizable organic N resides in the upper 30-cm layer, but significant amounts often occur in the (30 to 45)-cm layer. Hence, N mineralization potential was measured for each 15-cm layer to a depth of 45 cm. For each site, estimates then were made of the amounts of N mineralized per month, taking into account the average air temperatures and the estimated residual available water supply present in the root zone.

The multiple regression of N uptake (Y) on residual nitrate (X_1) and on estimated N mineralized during 6 months (X_2) showed significant contributions from both sources. Moreover, in the equation (1971 data), $Y = 0.75X_1 + 0.69X_2 + 1.3$, similarity of regression coefficients suggests that the relative availabilities of the two sources of soil N did not differ appreciably. Thus, we conclude that reasonable success was achieved in estimating N mineralized during the season in view of the approximations used in the analysis.

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